

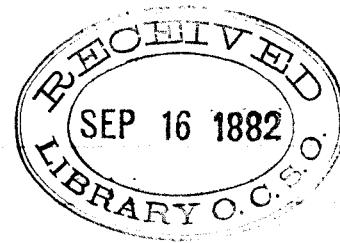
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Derham

De Motu Soni (Sound)

Translated by

J. B. Welling



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# **National Oceanic and Atmospheric Administration**

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De Motu Soni

by



Rev. W. Derham

Philosophical Transactions, London 1708 - Vol. XXVI.

Translated

by

Dr. J. B. Welling

Experiments & observations on the motion of sound, and other things pertaining thereto, made by the Reverend Mr. J. W. Dabham, Rector of Upminster Church and Fellow of the Royal Society of London.

- 
1. Disagreement of the most celebrated authors about the progress of sound & the reason of my undertaking.

The most celebrated philosophers have thought it worth while to inquire into the delightful & mysterious reasoning about sound, and especially about its motion and rate of progress; & since the discrepancy among their observations is great, partly that I might remove my own doubts, partly that I might find amusement in my leisure hours

I have endeavoured, as far as in my lay, to unfold and decide the whole matter.

And since my instruments are most suitable, and my opportunities for testing the matter were not to be despised, I suppose myself, in doing so, to be merely performing an appropriate duty, or to pay a debt to the philosophical world, especially to our most famous Royal Society, which has designed to admit me into its number.

The dissent among the most celebrated authors about the velocity of sound can be seen by a slight glance at the following table, in which is exhibited, (in English feet) the space they ascribe to the progress of sound in a single second of time:

|   | feet |                                      |
|---|------|--------------------------------------|
| Sir Isaac Newton  | 968  | Prin. Ph. Nat. Math. Lel. 2 prop. 50 |
| Hon. Mr. Roberts . . .  | 1300 | . Philosophical Transactions N. 209  |
| Hon. Mr. Boyle . . .  | 1200 | . Essay of Sanguid Motion p. 24      |
| Mr. Walker . . .  | 1338 | . Philosoph. Transactions N 247      |
| Messrs . . .  | 1474 | . Ballistic Prop. 39                 |
| Messrs Flamsteed & Halley<br>Distinguished Citizens of Florence | 1142 | . Exp. per Acad. del. Cimento p. 141 |
| Frenchmen . . .   | 1148 |                                      |
|   | 1172 | Dr Hamel Hist. Acad. Royale          |

Between the last and the next to the last of these estimates, the disagreement is not considerable, and the estimate of the French authorities is not much greater than these two. But among the rest the disagreement is great; and the reason of the discord manifestly is that it arises either from a defect in the instruments used or from the inadequate distance at which the observation were made, or from the effect of wind.

The apparatus by which some of these distinguished men made their measurement was not automatic, but was a ball suspended by a cord, which vibrates seconds. Now to all who are versed in such matters it is obvious that the ball is much less convenient than an automatic instrument, and is not so accurate; since it is necessary that the eye should first be engaged in observing the flash & then should glance towards the ball or pendulum — a process which consumes time and produces confusion. This fact then

considered in connection with the slowness of our sense, & of our perception or attention, may produce a great error, as is well known to those who have made experiments concerning these matters. Especially is this the case if 2. The interval between the sounding body and the observer may have been small. It is manifest, however, that the most of these distinguished men made their experiments at the distance of only a few feet, & made their measurements by the return, or echo of the sound. For some of these observers scarcely extended their measurement beyond six or seven hundred feet, and others not beyond a mile. But I have always observed that an ambiguity arises in a distance so small, though the best apparatus may be used. Because the slightest error in distance so very small is to be considered comparatively great. For the pendulum, perhaps has passed through the half of its sweep or arc, from the last vibration when the sound may have been first emitted; but we count that beat as if it had been a full

and complete vibration; or perhaps we may anticipate the vibration. And after the sound reaches us, we may perhaps count more or less than is right.

Or, if the distance shall have been long enough, still an error may arise from that very circumstance, if

3. Account be not taken of winds — about which more hereafter. These are the certain, inevitable & perpetual inconveniences which accompany the measurement of the progress of sounds — inconveniences which in small intervals, as I have said, especially if the instruments be bad, are able to produce great errors; and without doubt they have been the greatest cause of the disagreement among authors so eminent. But one can see how very near is the agreement among the distances assigned by the last three observers in our table — a fact which doubtless arises from the circumstance that they were furnished with good automatic instruments, in

the use of which the ear is simply occupied with catching the vibrations of the pendulum, while the eye marks the flash or some other indication of the sound. These observations, besides, were made at long distances, in which a petty error will not be of great account. For the observations of the very celebrated Messrs. Flamsteed & Halley were made at a distance of almost three miles, (a few perches more or less being excepted), from the Royal Observatory on Shooters Hill, and the sound came to them in  $13\frac{1}{2}$  seconds. The gentlemen of Florence, who were also celebrated members of the Academy of Experimentation, (Acad. del Limento), made their experiments at about the same distance and some experiments at the distance of only a mile. And, finally, the very celebrated Messrs Leurini, Picard, & Romer made their experiments at a distance of 12 80 French toises, which is more than one English mile & a half.

That the truth might be brought to light in the midst of the aforesaid disagreements, I have made very many experiments at various distances, to wit, from one mile to twelve miles or more - And for the purpose of measuring the time, I have a very accurate portable instrument which is automatic and furnished with a pendulum vibrating half seconds.

That I might ~~not~~ proceed the more safely I proposed to myself the following questions to be discussed:

1. How great is the space which sound traverses in a second or other interval of time?
2. Whether a gun fired towards an observer sends the sound in the same interval of time as when it is fired in the opposite direction?
3. Whether in every state of the atmosphere when the mercury is rising or falling in the Barometer sounds traverse the same space in the same intervals?

4. Whether sounds are propagated with greater velocity by day than by night?
5. Whether a favoring wind accelerates sound and an opposing wind retards it - That is, whether winds affect sound at all, and if so, in what manner?
6. Whether sound is propagated with a greater velocity in a tranquil atmosphere than when the wind is blowing?
7. Whether a strong wind blowing crosswise accelerates or retards the velocity of sound?
8. Whether sounds have the same velocity in summer and winter by day and by night?
9. Whether also in snowy and in clear weather?
10. Whether a great & a small sound have the same velocity?
11. Whether at all [angular] elevations, viz.: horizontal, ten degrees, 25 degrees, and so on to 90 degrees, the sound of a gunshot strikes the ear of an observer at the same interval

of time?

12. Whether sounds of all kinds, i.e. of guns, bells, hammers &c., have the same velocity?
13. Whether charges of powder varying in strength produce a variation in the velocity of sound (*An variae pulvris pyrii vites motum toni variant*)
14. Whether on the tops of high mountains and in valleys, that is, whether in the highest and lowest parts of the atmosphere, sounds travel the same space in the same interval of time?
15. Whether an upward and downward sound have the same velocity; that is, whether it descends from the top of a mountain to its base at the same rate as it ascends from the base to the top?
16. Whether sound is propagated in the beginning with greater velocity and in the end with less, as occurs in many other violent motions.
17. Or whether, on the contrary, it is

uniform - That is, whether or not it is propagated half the space in half the time, one fourth of the space in one fourth of the time &c.

18. Whether in all regions northern or southern - in England, France, Italy Germany &c - sounds have the same velocity.

19. Whether sound passes from place to place in a straight line, (i.e. by the shortest path), or according to the (irregular) superficies of the interjacent land.

For the settlement of these questions I asked some kind friends of mine, (whose favors I here most gratefully acknowledge) to fire muskets from towers and other high places at a distance of one, two, three and <sup>even</sup> as far as eight miles, (which I have found to be the greatest distance at which I could hear the sound of a gun in these parts, covered as they are with woods &c). These

use to me.

Musket shots were of great; But what especially answered my purpose was the common (Sakers\*) which are used at Blackheath in training the raw recruits who are to serve the artillery of our most illustrious queen. I could see the flash and hear the report of these cannons from the town of my church; sometimes also I made use of a telescope. And hence I have devoted myself with all care and diligence to the observation of these cannons since February, 1704.

After a few observations made in the midst of their discharges, I took measures for making a certain particular experiment through the courtesy of the late Baron Granville then the Governor of London Tower and of other eminent men who on that Tower serve the interests of the royal artillery, (and whose favors I here most gratefully recognize).

\* The saker is a species of small ordnance. Translated

Two cannon (Sakers) were placed side by side one with its mouth towards me the other with its mouth reversed. Here two cannon on the 13<sup>th</sup> February 1704 were fired every half hour from 6 o'clock P.M. to midnight, while a gentle breeze was blowing directly against the sound. The interval between the flash of each gun (which flash I could see with the naked eye) and the arrival of the sound was always about 120 or 122 half seconds - I have said 120 or 122, since the sound came to me duplicated - that is the first sound came within 120 half seconds (which was a weaker sound) and the second within 122 half seconds (which was a stronger sound) and in the same manner, through the whole time of the observation, the crash of each cannon came in a duplicated form.

This reduplication of sound seems to me an echo, reverberated, as I think,

from the watermill at Blackheath, or from the houses situated in its vicinity. I have no reason for doubting about this point except the contrary opinion of a learned friend & sagacious philosopher who believes that there is no echo to be heard save that produced by objects reflecting sound near the observer, instead of its being produced by those near the sounding body - or other distant objects.

The next disquisition, therefore, will be, Concerning sounds vibrated from a distance, or the distant echo.

Perhaps this disquisition will be considered a digression but since it pertains to the subject of sound I hope that a few observations on this subject will be ungrateful to ingenious minds. And in the first place I believe that this [the fact that the echo comes from afar] is not contrary to the laws of the echo. In the second place it is to be remarked

that this double sound came directly from Blackheath; for, of the two sounds, the former did not come from that quarter, and then a second sound, (after the manner of an echo), came from ~~somewhere~~ where else, i.e. either beyond me, to the right of me, to the left of me or from any different direction. I have often observed the same thing when big guns were fired from ships in the river Thames, (especially if the air was clear & still), at the evening and in the morning when the watch-guns are discharged. After the crash of the gun has struck my ear I have heard it running far away along the river, and booming through many miles from the bank, from the mountains, and from the rocks thickly studded along the Kent County coast. "These all", says my friend, "come from the reverberation of the houses, &c., near you." But to say nothing respecting the weakness of a sound after it has traversed very many miles, and respecting its incapacity

if it has come <sup>so</sup> far, to be rebounded by sound-reflecting objects near the observer, rather than by sound reflecting objects situated near the sounding body — to say nothing about these things, I will give one or two examples from which it will plainly appear that an echo made by sound-reflecting objects near the sounding body can be heard through many miles as well as the primary sound, — sometimes even clearer than the latter.

I have often observed that the heavy guns fired from ships in the Thames at evening, about Deptford & Cuckold's Point, send forth for the most part a crash that is duplicated, triplicated, quadruplicated, or even still more multiplied, and that the later crashes are more sonorous. And when I have gone here and there a hundred and twenty five paces, or even a quarter of a mile, or half a mile in a transverse direction, the sound was still the same. I remember that on the 8th of last March many cannon

were fired, somewhere between the aforesaid Deptford & Cuckold's Point, from a ship in the Thames, which I saw from my church.

The crash of these was repeated five or six times, in this manner: ~~77.779~~. Between the flash and the sound I counted 122 half seconds - the wind blowing crosswise. At that time, therefore, the guns were distant from me more than 13 miles. The first two reports were much weaker than the third reports, but the last reports were ~~the~~ much the most sonorous of all. And when I had gone across a quarter of a mile towards the right, there was still the same multiplied sound, and when towards the left, it was still the same. And moreover, in some of my halting places, besides the multiple sound, I clearly heard a weak echo re-verberated from my church, <sup>or</sup> at the adjacent houses. Indeed, I then made the same observation, as often as the guns were fired.

Another observation of this kind was

made on a certain Sunday, about two or three years ago, from the sound of a heavy cannon fired somewhere on the river Thames, this side or beyond the town of Gravesend. The crash of this gun was multiplied at least 8, 9, or 10 times, according to this score: ~~B B B B B B B B B~~ 9. Very many persons who at that time were on their way ~~far~~ to Divine Worship supposed that this multiplied sound was the crash of many guns from a ship engaged in battle but, as I think, it was nothing else than a many-voiced echo from the sound of a single gun as it was fired, or from the sound of another and another reverberated by the many adjacent ships or by the shore. What makes for ~~reverberates~~ my opinion is the fact that I was not the only one who heard it (I was walking at the time in my garden) - but also many other persons who were far distant. Mr. Barrett likewise an ingenious & learned member of our Royal Society,

heard the same repeated sound at his house at a distance of about four miles from Uptonister, where I heard it. From all these considerations it clearly appears that the opinion of my aforesaid friend (so worthy to be respected on many accounts) is false.

### Concerning Echoes or the Reverberation of Sounds in the Air

To these remarks on echoes I hope it will not be unacceptable to add an illustration from the reverberation of sound sound by aerial particles, which will confirm what has been said. When I have heard the crashes of heavy artillery, especially in a still and clear atmosphere, I have often observed that a rumour high in the air preceded the report. And in thin fog I have often heard the sounds of cannon running in the air high above my head through many miles, so that this

rummer has lasted 15 seconds. This continuous rummer, in my opinion, comes from particles of vapor suspended in the atmosphere, which resist the course of the sound-waves and reverberate them back to the ears of the observer, after the manner of undefined echoes, which we call a rummer in the air. When these facts are duly weighed it will be manifest that echoes made at a distance are capable of being heard, and that that aforesaid reduplication of the crash of artillery on Blackheath came without doubt from Blackheath itself, as I have just asserted.

Concerning the sounds of gunshots fired in every angular direction, &c  
To return from this digression concerning the reverberation of sounds, I will proceed to my observations concerning their velocity - observations

which I have derived from <sup>my</sup> many experiments. And what I have just now suggested respecting the sound of the artillery on Blackheath, I have found in all other cases, viz. that the motion of powder is neither swifter nor slower whether the cannon be fired towards the observer or in the opposite direction.

Likewise, in all positions of a musket, whether horizontal or perpendicular, and at all elevations, ten degrees, twenty degrees, &c., there is no variation in the sound of its discharge. So true in this matter is the observation of those famous gentlemen connected with the Academy of Experiments in Florence.

The force also of the powder, whether it be strong or weak, and the greater or less quantity of the charge, though serving to increase or diminish the sound, have no effect in accelerating or retarding its motion.

5. Concerning the velocity of sound in any state of the atmosphere and any

time of the year.

Kircher says, that he always found the velocity of sound to be different at different times, at morning, at midday, at evening & at night. But I, relying on a better chronometer and using a more suitable distance, never have found that the velocity of sound is different at these times, but in all weather, whether the atmosphere be clear and serene, or cloudy & turbid; whether snow is falling or fog, (which both powerfully blunt the audibility of sound); whether it thunders or it lightens, whether heat or cold dries the air; whether it be day or night, summer or winter; whether the mercury is rising or falling in the barometer - in a word I may say that in all changes of atmosphere whatsoever (winds only being excepted) the velocity of sound is neither greater nor less. The sound is only more or less clear from the variation of the medium, and perhaps the last deceives the sagacious Kircher.

Hence it follows that the conclusions drawn by Mr. Walker from his ingenious observations and from those of Dr. Plot, and of Kischer were erroneous.

6 concerning the velocity of a strong + of a weak sound, and of the sound of different sounding bodies.

Though Kischer thinks otherwise I do not doubt that the sounds of all bodies - of muskets, bells, hammers &c, have the same velocity. In the year 1704 I compared the beatings of a hammer and the crack of a musket at the interval of a mile (the greatest distance at which I could hear the sound of a hammer), and I found that the sound of both reached me in the same time, as also that they traversed  $\frac{3}{4}$ ,  $\frac{1}{2}$  +  $\frac{1}{4}$  of the same space in  $\frac{3}{4}$ ,  $\frac{1}{2}$  +  $\frac{1}{4}$  of the same time.

As regards strong and weak sounds I do not doubt that they traverse the same space in the same interval of time. This fact

will be in a measure apparent from the following experiments:

January 13, 1704. The master gunner of Tilbury fort at my request fired two gun shots in succession, and a heavy cannon in which he had well rammed a charge of powder. The report of all these reached me at the distance of about three miles in the same time.

The master gunner of England\* also on the 11th Sept. 1705, after sunset, as a matter of favor to me fired on Blackheath some muskets, some heavy Cannon, (Sakers) and some mortars. I could not hear the muskets on account of the great distance, or because the air was not sufficiently serene. But I heard the sounds of the cannon & of the mortars in the same interval of time, though the crash of the mortar was much more torpid and weak than that of the cannon. Notwithstanding the fact that I used the greatest care in these experiments,

\* "The master gunner of England" was the title of the senior master gunner in the <sup>period - translator</sup> admiralty service of England at this

Nevertheless wished afterwards to try them over again at greater distances, but the opportunity was wanting. I leave this matter therefore to be better tested by others.

### 1. Concerning the Uniformity of the Velocity of Sound.

The next observation was concerning the uniformity of the velocity of sound. I have found this to be the same as the illustrious Academy of experimentation (Academia del Lincei) has already defined. That is, sounds travel half the space in half the interval of time; one fourth the space in one fourth the interval of time and so on. This fact will be plain from the examples in the following table:

| Place where the<br>Guns were fired | No. of<br>Influences<br>of the<br>Pendulum | Distance of Places          |                      | Direction of the Wind             |
|------------------------------------|--|-----------------------------|----------------------|-----------------------------------|
|                                    |  | By<br>Trigonometry<br>miles | By<br>Sound<br>miles |                                   |
| Hornchurch Church                  | 9  | 0.9815                      |                      | Crosswise                         |
| North Ockendon Church              | 18½  | 2.004                       | 2.                   | "                                 |
| Upminster Mill                     | { 22 ½<br>23                               | 2.004                       | { 2.004<br>2.048     | Favorable<br>Crosswise (with sun) |
| Little Warley Church               | 27 ½                                       | 3.                          | 2.097                | Strongly favorable                |
| Reinham Church                     | 33 ¼                                       | 3.058                       | 3.059                | Crosswise, i.e.                   |
| Worley Mill                        | 33   | 3.058                       | 3.057                | Crosswise                         |
| Dagenham Church                    | 35   | 3.058 <sup>.85</sup>        | 3.078                | Favorable                         |
| South Wood Church                  | 45   | 4.059                       | 4.086                | Crosswise                         |
| East Thorndon Church               | 46 ½                                       | 5.009                       | 5.003                | Slightly favorable                |
| Barking Church                     | 70 ½                                       | 7.007                       | 7.062                | Favorable                         |
| Blackheath Cannon                  | 116  | 12.005                      | 12.055               | Crosswise                         |

The distances of the places marked in this table from Upminster (where I made my observations) I measured with as much accuracy as I could either by the surveyor's rod or by trigonometrical art. And from the great consonance between the distances measured in this way and by the velocity of sound, the excellence of my instruments as also the truthfulness of my calculations and observations is set in a clear light. For the difference between the distances

ascertained by measurement, and taken from sound, either disappears entirely, or is that of only a very few hundredths of parts, unless when there may have been a favoring wind (the case of south Neal church being excepted, concerning which hereafter). So, too, in the observations made from the churches at Dagenham, Wards, Thorndon, & Barking, the distances marked by sound seemed a little shorter because the wind accelerated the sound. But in marking up this column of distances by sound, I have allowed nothing on account of the acceleration of the winds, but have simply divided the number of the vibrations, or half seconds, by  $9\frac{1}{4}$  or  $9.25$  (the number of half seconds in which sound ~~travels~~<sup>traverses</sup> a mile).

The equable rate of the motion of sound is also manifest from this table, as will appear from a comparison of the vibrations and of the distances, or from the column of the distances alone as derived from sound.

But that nothing might be wanting

in confirmation of these facts I made a journey to Foulness Sands on our Essex Coast. These Sands, washed & covered by the daily tides of the sea, make a great and smooth plain for many miles. Upon this plain I measured off only six miles, because neither the tide nor my leisure permitted that I should measure a greater distance. At the end of almost each mile I made experiments by the firing of muskets, not without great peril to my life from the influence of the sea & the darkness of the night.

From these experiments I found that all my former observations were most exact and true, to wit, that sound traverses one mile in  $9\frac{1}{4}$  half seconds; two miles in  $18\frac{1}{2}$  half seconds, three miles in  $27\frac{3}{4}$  half seconds &

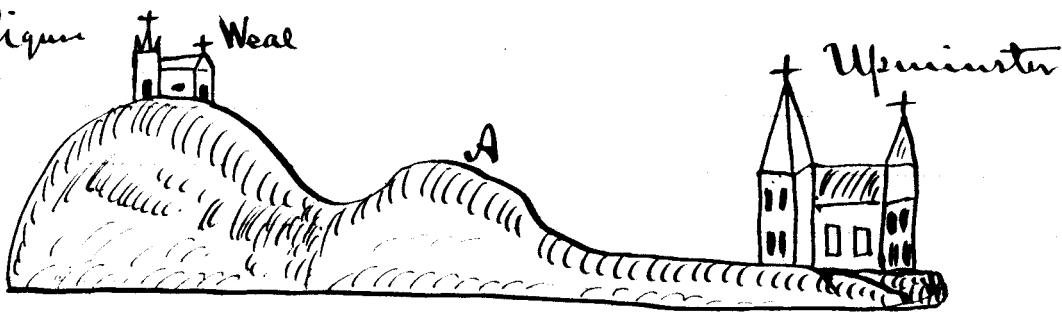
8. Concerning the upward and downward motion of sounds, or concerning the ascent and descent of sounds. Likewise whether they pass from place to place in a straight line

or according to the superficies of the interjacent land.

As regards questions 15 & 19, I frankly confess that I have never satisfied myself on those points by any of the experiments which I have hitherto made.

In the first place let us treat on the progress of sound by the shortest path, under the head of question 19. The reason for doubting about this was the discrepancy between the distance from Weal to Upminster by trigonometrical measurement & by sound, as is exhibited in the preceding table. The trigonometrical measurement was taken in so many ways & with such good angles, that I can have no doubt about it. But since the distance as measured by the motion of sound seems to be greater, and since the superficies of the interjacent ground takes on a form like that exhibited in this figure,

figure St. Weal



I have in consequence, somewhat doubted whether sound may or may not move a little crookedly, that is, whether or not that intervening elevation at "A", by the resistance which it offers to the waves of sound beats them back and retarded them -

That I might in some way solve this problem I took care that experiments should be made with the sound of a musket from the top of Sandom Hill to the valley below, <sup>at</sup> a distance of 3.79 miles. The distance was well measured trigonometrically, from angles & from a base line sufficiently large; and the experiment was made while a gentle breeze was slightly opposing the sound. Between the flash and the report I counted  $35\frac{1}{2}$  half seconds. This

number squares so exactly with the distance, & so nearly agrees with other experiments that it cannot be doubted that the sound descended from the top into the valley by a straight <sup>line</sup> (through the air), and not according to the curved superficies of the interjacent ground.

I believe therefore that there was some error in the oferred observations at Wral, since neither in the last experiment at Langdon, nor in any others, have I observed anything like it.

As regards the upward and downward motion of sound, that is, whether sounds are borne with equal tenuor and at the same rate from the top of a mountain to the bottom, I scarcely hope that I shall ever satisfy myself or any body else. For neither in Essex nor in the contemnious parts are any hills found high enough from which one may make sufficient experiments to this end. In fact the

highest of all which it has yet been my lot to see, (such as those which they call the <sup>a</sup> Longdon hills), do not much exceed 300 ft. For I measured the height of these hills both by trigonometry and by a portable barometer, & I found it to be by the former mode 363 ft high by the latter mode. . . . .

On a former summer, however, when I was making a journey in the western parts of the Kingdom, I determined to try an experiment on a certain hill whose altitude I ascertained by measurement a few years previously to be (unless my memory deceives me) about 1875 feet. At a time when the wind was blowing across the path of the sound, but so gently that it would not extinguish a lighted candle, I ordered some muskets to be discharged at the base and at the top of the mountain, and I perceived that the sound reached me from each in about almost the same interval of time. If I observed any slight discrepancy at all it seemed to consist in this that the sound

may have ascended somewhat more swiftly towards the mountain than it descended from the mountain. But to speak according to the fact, I was scarcely able to measure the time with the accuracy which is due, since unluckily, it had turned out that the chronometer which I used had been somewhat disturbed by a concussion received on the journey.

Hence I leave this experiment to be tried more successfully and certainly by others. And I would that the votaries of higher culture & philosophy among the Italians, (in whom has been implanted a curious felicity of genius) might be willing to try this same experiment on the Alps.

#### Concerning the translation or motion of sound in Italy.

Inasmuch as I have made mention of the Italians, it seems not irrelevant to recite certain observations and experiments made in Italy on my account by that very acute, learned and accomplished

friend of mine Dr. Newton, the envoy of her Britannic Majesty at Florence. The occasion of these was as follows:

The late ingenious and excellent Richard Townley, Esq., (a name familiar and grateful to our renowned society) had signified to me by a letter written in the year 1704, that "ounds are rarely heard as far at Rome as in England & in our northern regions." He said particularly that while he was staying at Rome, on an occasion when some cannon of the castle of St. Angels were fired on account of joyous intelligence, & when he was standing on Mount Trinita, he has observed that the sound was much more languid in that situation than in any other location at the same distance. And after death of Dr. Newton, his brother reported to me, in writing, that in the year 1688, "when on leaving Rome, he repaired, for a season of recreation to Castel Gandolfo (a certain higher location near lake Albano, about 13 Italian miles from Rome), he had observed

that the sound of the heavy Cannon booming from the aforesaid Castle of St. Angelo seemed when reduced in volume and weak. Also at another time when he was passing around the walls of this same castle in a carriage, and when the great guns were bellowing from it, they seemed to send forth a sound which, as ~~they~~ observed, was neither in quality nor volume like that observed elsewhere."

Since these things had been noticed by two men of no common intellect, and since the phenomenon itself seemed entirely new and unusual, the desire entered my mind of enquiring what might be the cause of it. I therefore wrote to the very distinguished Dr. Newton, whose praises I have already celebrated, and he in the month of October, 1706 was good enough to report to me ~~what~~ what he and also what his friends had observed respecting this matter.

He recites that on a journey from Bologna towards Florence he heard at the city of San Michele in Bosco, near Bologna the sound of the firing of Cannon. These

Cannon were forty miles off, being fired at Mirandala, which all knew, and they held in siege. And on the following night he heard the same sound while he was riding over night in the Apennines, (twenty miles further off.)  
But I

Cannon were forty miles off, being fired at Mirandola, which a French army then held in siege - And on the following night he heard the same sound while he was resting over night in the Apennines, (thirty miles further off.)

But the observations and experiments which the same very eminent man through his politeness & benevolence, caused to be made by others, justly claim for themselves a particular specification as well as my best thanks for these favors which his excellency has conferred upon me. When he received my letter at Florence he disclosed what I wanted to a certain nobleman who was at the same time an eminent philosopher; and he in turn communicated these wishes of mine to the Grand Duke. "The Grand Duke as he says, in accordance with his singular love of the arts and of

learned pursuits, as also in accordance  
 with that gracious indulgence towards  
 their votaries which he has received by  
 inheritance from his ancestors along  
 with his sceptre, immediately gave  
 orders that experiments should be  
 made for the sake of fully satisfy-  
 ing me on this point; and he set  
 Joseph ~~Amman~~<sup>Torriani</sup> a renowned philosopher of Pisa,  
 and a man skilled in every one of the more  
 liberal arts, over the inspection and direction  
 of these experiments. The memoirs of this  
 most honorable gentleman our most  
 honorable envoy has designed to write  
 out at length for me. But the gist of  
 the matter amounts to this: After  
 having premised with equal caution  
 and ingenuity very many things  
 which might produce a great  
 difference in the progress of wounds  
 he at length proceeds as follows:  
 "In the lower fortress of Florence a  
 culverin was fired frequently be-

"tween the first and the third hour of  
"the night. Certain men at the same  
"time were kept at Seghoma who were  
"ordered diligently to observe whether they  
"could hear its report. Of these men,  
"some who had been stationed at the eight-  
"house and at Marzocco heard no sound;  
(perhaps because the roar of the sea  
"obscured the sound); but others who  
"were standing on the bastions of  
"the old fortress (which they call Dorjim)  
"and those who had been sent to Mount  
"Rotondo (which is about five miles  
"from Seghom in the direction of  
"Mount Nero) caught up the sound in  
"their ears. And as often as the gun  
"was fired its report was clearly heard  
"in these same places. Now the distance  
"of this fortress of Florence from Mount  
"Rotondo in a straight line is reckoned at  
"not less than fifty five miles. And it is  
"worthy of note that the interjacent country  
"was studded with many hills, which must

" needs have somewhat obstructed the path  
" of the sound. Of these considerations  
" it ~~should~~ <sup>must</sup> be added that on the same  
evening a west wind was gently blowing  
which, (since Leghorn is situated to the  
south southwest with respect to Florence)  
may justly be supposed to have slightly  
impeded a free expansion of the sound.  
In order however that an open place  
and one lying level in all directions  
might be obtained, that tract of the  
sea was selected which lies between  
Leghorn and Port Ferrais, the distance of which,  
according to the calculation of the most  
skillful sailors, is set down, at sixty  
miles. The report, however, of artillery not in-  
frequently reaches from Leghorn to this Port, &  
the places in its vicinage. Nor is there need  
of favoring winds to promote this passage  
of sound, in order that it may be surely  
heard. Indeed any wind whatsoever,  
whether it be favorable or adverse, is  
equally an impediment, and renders

the sound less audible; it may be because  
the roar of the sea, agitated by this cause,  
is more a disadvantage than the current  
of the air blowing in the same direction  
is an advantage. Hence it is that  
the sound is heard only when the wind  
is entirely still or is only murmuring  
very gently - when the air is serene  
and the sea tranquil. Moreover,  
indeed, <sup>all</sup> is it heard indiscriminately  
from ~~the~~ points, but from those only  
which are a little the more elevated  
such as the two bulwarks which are called  
Stella and Falcon and the place called  
Stulini. Moreover it is required that the  
observer should be as attentive as possible,  
& should not be hindered and troubled  
by the voice or clamor of persons  
making a din around him. But then  
equally by day and by night he may hear the  
sound provided the atmosphere be clear and  
still - the only difference being that the sound  
hears somewhat stronger and clearer in the

" night time, when no noises occur such  
" as are often wont to disturb the ears)  
" by day.

" Moreover, it has been reported to us by  
" most credible witnesses that many years  
" ago when an insurrection was raging  
" at Messina and the city was closely besieged  
" the sound of the guns startled the ears of the  
" inhabitants of Augusta and of Syracuse.

" Likewise when the French were shaking Genoa  
" with heavy siege guns it is certain that the  
" sound of the cannon reached as far as  
" Mount Nero which overhangs Leghorn.

" From these observations I am inclined  
" to believe that there is no difference in this  
" regard between Italy and the Northern regions.

" But as regards the other question - whether  
" a wind blowing directly or adversely accel-  
" erates or retarded sound - it is not in my  
" power as yet to give a certain reply. For  
" the experiments which I have instituted  
" and by which I had hoped that the truth  
" would be explored, do not suffice for settling

" the question. In fact during the summer time (when  
" ~~for~~ the most part the winds by day blow from  
" the sea and from the west, while when evening  
" comes on they are generally still), the most  
" suitable occasions for frequently and certainly  
" testing the matter were wanting to me. I hope,  
" however, that towards the close of the year,  
" after weather of another kind shall have super-  
" vened, I may obtain more favorable opportunities  
" for instituting and testing experiments of this  
" kind with greater success and frequency, as  
" also with greater accuracy. But for the present  
" it must suffice to report what happened  
" to me on the 10<sup>th</sup> of August last past, when  
" I was permitted to ~~try~~ the following experi-  
" ments:

" A column of a certain kind (60) [columina  
" quaedam (60)] was placed on ~~a certain~~ the  
" curtain of the lower fortress of Florence,  
" and was so planted there that its mouth  
" pointed towards Artemino, which is the  
" country palace of the Grand Duke of  
" Tuscany, situated on a rather high hill,

and opposite to the west side of the  
aforesaid fortress, from which also  
it is distant about 12 miles. I selected  
a particular day when the west wind was  
blowing rather briskly, so that the veloc-  
ity of sound might be resisted by a  
contrary wind. But this helped the  
matter only a little, for towards evening  
the air was entirely still, or at least was  
agitated with such a slight breeze as  
would not have put out the flame  
of a candle. Having left at this  
spot certain observers skilled in  
these inquiries to whom I had previously  
given in charge what they should most  
particularly attend to, I proceeded to the  
aforesaid place of Artemino, where the  
very Honorable Envoy had preferred to be  
stationed. According to my order the  
Culverine was frequently fired between  
the first and third hours of the night,  
and I plainly counted 49 seconds between  
its flash and its report. We also fired

Some cannon at Astemino, and the  
 aforesaid obrawus, whom I had left in  
 the fortress, counted between the flash  
 & the report of three only 48 seconds.  
 Hence it appeared that the sound  
 was borne from Astemino to Florence  
 only a second more rapidly than  
 it was borne contrariwise.

I do not so fully confide in this observation of  
 mine that I would venture to refer this very  
 small difference of velocity to the force of a  
 favorable or of an opposing wind. In fact  
 a mistake of the observer himself, as he counted  
 the vibrations of the pendulum, might per-  
 chance have given occasion to it. This  
 at least might readily occur, for it must  
 needs often happen that he should not see  
 the flash until after the ~~obscuratio~~ vibration  
 of the pendulum has begun, and that he  
 should hear the report of the sound before the  
 vibration has been completed; so that in this  
 way he may make his calculation too  
 large by one vibration, whilst in point

of fact the interval of time is precisely the same both ways.

I was hoping however that on the next morning a contrary wind would perchance arise, for often at this point, at least with the first dawn of day break, a wind is accustomed to blow from the east) which would better serve for the experiments I had begun. I had ordered therefore the Culomine to be fixed again as soon as day should have dawned, but the wind was propitious neither to my wishes nor my undertaking. In fact it had shifted only a very little towards the north quarter, in so much that the variation of the time and of the velocity of the sound could scarcely be perceived with such a slight change of the wind. I counted, therefore, the usual 49 vibrations of the pendulum, as before. In the mean time I hope thoroughly to try these same experiments as soon as more suitable weather shall occur, and as more frequent changes of the winds shall afford more convenient opportunities for trying them to better advantage, until at

"length I shall perfectly satisfy myself."  
As regards the space which sounds traverse  
in any given time my informants are  
not yet agreed among themselves, but  
from certain experiments they conjectured  
that the matter is as the experiments of the  
Accademia del Cimento signified."

So far this acute and skilful man, whose  
praises I need not repeat. From his obser-  
vations together with those which the  
very honorable and distinguished Envoy  
has communicated to me it is abund-  
antly clear that sounds can be heard  
much further in Italy than my before  
named ingenious friend informed me.  
For the excellent Envoy himself has heard the  
report of heavy guns at the distance of sixty  
miles. The guns likewise which at his  
request were fired at Florence were heard  
55 miles. The cannon fired at Leghorn were  
audible at a distance of 60 miles. Those  
which were discharged at Messina, as ap-  
pear from the geographical tables surpised

the ears of men who were distant nearly 100 Italian miles. The report of those which were fired in the Siege of Genoa traversed (as appear from the maps) more than 90 Italian miles [Ital. M. = 1.0277 English].

When all these facts are recalled to the mind and seriously weighed, I can scarcely avoid the belief that sounds are propagated no less widely in all quarters of the earth than in the northern parts of the world. Although the examples of a greater progress of sound are not wanting in certain northern quarters of the globe, A Danish nobleman, a servant of our Illustrious Prince of Denmark, has told me, in a conversation which we had together, that while he was living in Denmark he had clearly heard the report of cannon fired at Carlskrona, a distance, unless my memory deceives me, of 80 English miles. Likewise that very skilful man Dr. Hran, the physician of the most illustrious King of Sweden has communica-

ted a special memoir to our Royal Society respecting the guns fired at Stockholm when the obsequies of one of the Royal Princes were celebrated in the year 1685, the report of which traversed an interval of 30 Swedish miles, which are equal to about 180 English miles. At that naval battle likewise which was fought between England and Holland in 1672, the sound of the cannon struck the astonished ears of men through an intervening space of more than 200 miles, reaching as it did, across our island even as far as Salisbury and Wales.

What therefore both the Townly brothers observed is wholly special and peculiar to the aforesaid castle of St. Angels or at least to Rome. For it is not permitted to suspect either the perspicacity of their intellects or their conscientious carefulness. The diminution of sound which they observed (unless I suppose amiss) must

be ascribed either to the situation of the  
aforeaid castle, or to the interjacent  
houses (rising every where and on all  
sides in that very crowded city) onto the  
air of the city resounding from  
all quarters, or to adverse winds,  
or, in fine, some other like cause,  
which I leave to be attained by happier  
conjecture on the part of those whose  
lot it is to live there, or perhaps these  
men made their <sup>aforeaid</sup> observations in that  
state of the atmosphere in which sounds,  
although they have the most favorable  
winds, are nevertheless much more lan-  
guid than at other times when the  
winds are entirely adverse. And at one  
time I had furnished myself that an  
atmospheric condition of this kind always  
obtains at Rome, and not in other  
parts of Italy, until I fell upon the  
contrary opinion of Kircher, who says:  
"Here at Rome, wonderful to relate, when  
the north wind blows, echo or sound

acquires the greatest vigor; when the south wind blows it is weak; when the south-east and east winds blow, it is of a medium character."

But this condition of the air, since it affects sounds so greatly, it will not be foreign from our purpose to consider in detail. It is my purpose therefore, in the next place to treat more fully, on it, and to set forth the observations which I have made in the premises.

Concerning the various weakening and intensity (or audibility) of sound according to the different state of the atmosphere.

I have often observed in the summer when time, when the air has grown hot, that sounds appeared more languid than usual, and were exceedingly weak in their impression on the ear; while in weather of another sort, especially in Winter; if it happens to be freezing cold, the same sounds were much more piercing and shrill, and struck the ear more forcibly. Also, when the north or south-east wind was blowing (however adversely), I have observed the sounds to be clearer and shriller than if the wind was blowing from contrary quarters, as Kircher also observed at Rome. But this is not uniformly and always the case. Nor could I form any more certain conclusions from the inspection of a rising or falling barometer, as I had too confidently expected to do. For I discovered that sounds were sometimes very clear and shrill, sometimes very faint and languid, when the mercury was rising to the top; and, on the contrary, sometimes very strong, sometimes very weak, when the mercury was sinking to the bottom. A like uncertainty obtains with regard to clear and foggy air. In rainy and damp weather I have often observed that sounds are blunted, and that after torrential rains they acquire the greatest strength, as Kircher observed at Rome. But the contrary also often happens. For instance, on May 31, 1705. The air on this occasion was more clear and free of vapor than I remember ever before to have seen it. For such was the purity and liquid serenity of the atmosphere that I could clearly and readily perceive exceedingly remote objects. But nevertheless, I was not able to hear the cannon that were fired at that time on the grounds of Blackheath (if I except a single one whose thud reduced to a faint sound, I may have caught up my ears), although I could clearly perceive the flash of them all in the distance. And at the same time the current of the clouds and of the wind was setting in the same direction with the sound. Moreover, the breeze which was then blowing was a very gentle one, such as comes

scarcely ruffle the hair; and, ~~in~~ fine, all things necessary to promote the force and velocity of sound seemed to concur. But, on the other hand, when the state of the air and weather has been wholly changed - when everything seemed turbid and the atmosphere full of vapor - I have often heard strong sounds, and not less often have I heard them blunted and weak. The causes of these variations I leave to be inquired by others, since I confess that it equally exceeds the grasp of my mind to discover them and to assign what may be the proper medium or vehicle of sound - whether the ethereal and more subtle part of the atmosphere, or the vaporous and denser part of the atmosphere, or both combined. But, as regards thick fog, it is certain that they are dampers of sound in the highest degree. For sounds then seem to be for the most part very weak and blunted - a fact which very certainly proceeds from the interposed vapors and thick particles which compose fog. I have likewise observed the same concerning snowy weather, for when fresh snow has fallen on the ground sounds straightway grow dull, but when its surface has been covered with ice, the sounds suddenly become more acute, and I have heard bells ringing and cannon booming just the same as if there was no snow on the ground. My friend Townley was telling me not very long ago that he had observed (the like of which I have myself experienced) that when he was riding on horseback through a certain town the sound of bells, which were then ringing not far from him, was hardly able to reach his ears whenever a house covered with snow lay between him and the sound, so that he on entering the little town, was very much surprised that the bells should <sup>so</sup> suddenly be stilled while he was passing along the first houses that intervened, and that they should suddenly sound again when he was passing along the next vacant space. Indeed during the whole of his course in this town he observed that the sound of bells reached his ears or not according as buildings covered with snow were intervening or not.

But concerning these things more than enough has been said. We proceed to other matters of greater moment.

### Concerning the force of winds or their influence on the velocity of sound.

The illustrious academy of Experimentation at Florence found from experiments that the velocity of sound was neither retarded by adverse winds nor accelerated by favorable ones, but that, however the winds might blow, sounds always traversed the same space in the same time. Gassentii was of this opinion, and almost all the rest who have philosophized before or since.

Since, however, the contrary of this is plain from mere experience, these authorities must be corrected of error, into which they seem to have fallen for this reason, that their experiments were tried within a too short space. For it is very probable that these philosophers made their observations at a distance of only one or, at the most, of two or three miles. Hence I do not

wonder that their observations are faulty; but if they had tested the matter, as I have often done, at ten or twelve thousand paces, using accurate instruments, they would have easily recognized their error.

This common error, I myself, relying on the authority of these men, admitted for a long time, until at length, by a three years and longer observation of cannon on the Blackheath grounds, I luckily detected it. When, however, at first I perceived the sounds to come to my ears sometimes quicker, sometimes slower, the suspicious entered my mind that I had committed some error, either because I had less accurately counted the vibrations of the clock, or had badly observed the flash of the cannon, or from want of attention, had fallen into some other such like

error. But often the cannon were continuously fired, at my request, every half hour, from six o'clock in the evening till midnight, and I constantly perceived that the sound reached me, without any perceptible variation, in the space of a hundred & twenty or of a hundred and twenty-two half seconds, ~~because~~ — — — however much wind may have been directly adverse; while at other times, when the wind was blowing favorably, either directly or crosswise or obliquely, I found that the sound of the same cannon reached me in the space of 111, 112, 113, 114, 115, 116 or, at the most, of 117 half seconds, then at last I became thoroughly persuaded that there was a certain real difference which produced this variety in the observations.

Now is it only true that favorable or adverse winds accelerate or retard the

velocity of sounds but it is also true that, in accordance with the variety of the degrees with which they blow more strongly or more gently, so much the more or less do they promote or impede this velocity. For greater certainty respecting all these things I will subjoin in the following table certain special observations, which were made after I had before noted that the cannon on the Blackheath grounds ranged from Upminster about sixty degrees from the south, that is, that they inclined to the quarters of the compass a little beyond S.W. & W.

Table of the sounds of Cannon on the Grounds of Black-~~1~~  
heath, according to the variation of the winds  
and of the force with which they were blowing.

| Month,<br>Year<br>& day | Time of<br>day               | No of<br>second<br>intra-<br>tions | Direction<br>of<br>the wind +<br>rate of<br>velocity | Direction<br>of<br>the clouds | Height of<br>barometer | Remarks         |
|-------------------------|------------------------------|------------------------------------|--|-------------------------------|------------------------|-----------------|
| 1704                    |                              |                                    |  |                               |                        |                 |
| Feb. 11                 | 11½ A.M.                     | 119                                | E, 2   | E.                            | 30. 22                 |                 |
| 13                      | From 6 P.M.<br>till Midnight | 120<br>122                         | N.E & E, 1   | NE & E                        | 29. 99                 |                 |
| 1705                    |                              |                                    |  |                               |                        |                 |
| Mar. 20                 | 10 A.M.                      | 113                                | S. W, 7  | A.W.                          | 29. 30                 |                 |
| Apr. 2                  | 8½ P.M.                      | 114½                               | S & W, 1   |                               |                        |                 |
| 3                       | 10 A.M.                      | 116½                               | S. 4   | Lower S.<br>Upper W.W.        | 29. 80                 |                 |
| 5                       | 1 P.M.                       | 111                                | S.W & W, 7   | S.W & W.                      | 29. 20                 |                 |
| 13                      | 8½ A.M.                      | 120                                | N.E, 2   |                               | 29. 26                 |                 |
| 24                      | 5 P.M.                       | 116                                | S.W. & W. 0  | N. W.                         | 29. 59                 |                 |
| Sept. 11                | 6½ P.M. }<br>7 P.M. }        | 115<br>115½                        | W, 2<br>W & N, 2 }                                   | W. & N. }                     |                        | Saker<br>Mortar |
| 29                      | 10½ A.M.                     | 112                                | S. S. W,   | S. S. W.                      | 29. 38                 |                 |
| Oct. 6                  | 10 A.M.                      | 117                                | E. S. E. 1/2   | A.E.                          | 29. 34                 |                 |
| Nov. 30                 | 12 M.                        | 115                                | S. S. W, 4   | S. S. W.                      | 29. 10                 |                 |
| Feb. 15                 | 11 A.M.                      | 116                                | S. & W, 1  | S. W.                         | 29. 60                 |                 |
| 1706                    |                              |                                    |  |                               |                        |                 |
| Nov. 29                 | (11½ A.M.)<br>(12 m.)        | 116<br>118                         | S. W. 0<br>S.W & S. 1                                | { S.W. & W.                   | 30. 06                 |                 |
| Feb. 1                  | 12 M.                        | 113                                | S.W. & W. 4  | W.                            | 29. 83                 |                 |

[N.B.] The distance of the guns from the observer must be  
about 12 miles.  $11\frac{1}{2} \times 58 = 662\frac{3}{4} \div 5280 = 12\frac{1}{2}$  miles.

I have selected three observations from my many others, all of them being cautiously made, and each one repeated two or three times or often, so that what I have above said respecting their truth is abundantly and ine-dubitably manifest. For, from the experiments made on April 5 & Sept. 29 it is plain that the strongest winds push forward and hasten the velocity of sounds. For on the fifth of April, when the motion of the wind and of the sound was nearly coincident, and when the same wind was a little stronger (as is denoted by the figure (7) annexed, just as the cipher (0) denotes tranquil weather, and as the figures 1, 2, 3, 4, &c signify different powers of the wind) then, I say, the sound finished its passage in the space of 111 half seconds. But on the 24th, when the wind was blowing from the same quarter, & the air was still, the sound made the same passage in an interval of 116 half

seconds. So likewise on the 7<sup>th</sup>, of February, 1706 when the wind was blowing from the same quarter of the compass & was carrying the sound with it, but now with only half the strength, 113½ seconds elapsed before the sound made its usual passage. So, in fine, on Sept. 29, 1705, when a stronger & less favorable wind was blowing, the sound completed its progress within 112½ seconds. From which examples, & from others in the tables, it plainly appears that stronger winds assist the propagation of sound, but that lighter winds are less effective in promoting its propagation.

The same likewise is plain respecting those winds or currents of air which directly favor or obstruct the progress of sound - that they make its velocity quicker or slower - and where intermediate currents of air are blown, that they produce in like manner an intermediate

progress of sound, as measured by the vibrations of the pendulum.

The greatest difference which I have yet observed in the passage of sound through a space of about 13 miles amounts to about nine or ten half seconds, that is, when strong winds are aiding and only gentle ones are obstructing the sound.

But when only gentle winds, or almost none at all, are either obstructing or aiding the sound, then the difference does not exceed two or three half seconds.

After, in this way, I had perceived what force the winds have, both for accelerating and retarding the course of sounds, curiosity lead me to inquire into the velocity of the winds themselves.

And though the inquiry may be foreign to my subject it will, I hope, not be wholly ungrateful, as I hope to curious minds if I publish

in this connection certain observations  
on this point.

### Concerning the Velocity of winds.

In order to ascertain how large a space  
winds may traverse in any given  
time I have used in preparing  
my experiments certain bodies  
of the somewhat lighter sort, such  
as thistle down, light feathers, &  
which seemed better to serve my  
purpose than -

The instrument which is described  
for us in the Philosophical Transactions,  
"No. 24; or even that other more  
available one, recalling the figure  
of a mill with wings attached,  
invented ~~unless~~ & mistake, by our  
most acute friend, the late Dr. Hooke,

From very many experiments which I have  
made, with the aid of the lighter sort of  
bodies, when the winds were blowing

with different degrees of force, I have found that the most violent wind traverses scarcely 60 miles an hour. For so ample on the 11th of August, 1705, the violence of the wind excited such a tempest that it almost over-turned the windmill itself near the spot where I made my observations [The different degrees of the force of the winds (as has just been seen) I have, for the most part, noted with these figures: 0, 1, 2, 3, 4, 5, 6 up to 10, 15 or still higher degrees] Now, I have estimated that the force of the above indicated wind answers to about 12 or 14 of these degrees. And from very many reiterated experiments I have considered that that tornado traversed about 33 feet in a half second, or 45 miles an hour. And hence I gather that the fleetest and most tempestuous wind (- that very violent wind which raged in the month of November, 1703, not being excepted) does not traverse more than 50 or 60 miles an hour.

After we have measured the velocity of the rapid ~~winds~~, it is not difficult to conjecture what may be the velocity of less rapid ones. For I have equally marked the course of these, and from various experiments I have convinced myself that some of them accomplish 15, some 13, others many more, and others many less miles per hour; while some are propagated with such a slow motion that they move scarcely a single mile an hour. Moreover, other winds are so sluggish that one may easily outstrip them while making a journey on horseback or on foot. This fact is apparent to our senses, for when we anest our steps we perceive a soft breeze gently扇ing us, but if we advance with it we feel none at all; while if we quicken our pace instead of a breeze accompaniment us and blowing in the same

direction with our movement, we plainly feel the air resting us; and blowing full in our faces. Likewise when the atmosphere is entirely quiescent and stagnant, if we chance to be walking or riding on horseback, we then perceive a gentle breeze pressing against us, with such degrees of force, in fact, as correspond to the rates of our own motion. And a breeze of ~~wind~~<sup>wind</sup> sound or current of air is borne with the same rate of motion or velocity when it presses against us with an equal impetus as we stand still, or linger in our track.

From these observations about the velocity of winds very many things not without utility, might be noted, but especially might we assign in view of them, one reason why the Mercury rises and falls for such a long time before clear

wrath or rain sets in.

But I will omit these considerations as being foreign to my purpose; and this only will I observe as to sounds, to wit, that while their motion is accelerated by wind it is plain that those parts of the atmosphere by which sounds are impressed or propagated are not the same as those from which winds are blown, but certain other more aetherial and volatile parts, as one may suppose. For the fleetest winds do not pass through more than sixty miles in an hour, but sounds travel more than seven hundred thousand paces in the same time.  $1142760 \times 60 = 68520 \times 60 = 4111200 \div 5 = 822.240$  paces (778 miles)

But if it be objected that winds do accelerate or retard sounds tis to be answered that this does not only proceed from the current or tendency of the windy particles alone but rather from the conjoint and coöperating motion of all the particles of the atmosphere both the thicker and

the aetherial. If the direction of the course or motion favor the waves of sound it is altogether in accordance with probability that the impulse of sounds should be accelerated by this cause; but if the direction is adverse that the impulse should be retarded.

### Concerning the velocity of Sounds.

After having in this way set forth the operation and effects of wind on the progress of sound & having spoken thus generally respecting the velocity of sounds, it remains at last that I should report the more special observations which I have made on this point. From what has been said, therefore, and from very many other things which we have noted before I conclude most decisively that sounds are propagated with the following degree of velocity, to wit, that they traverse the space of a mile or 5280 English ft.

are  $9\frac{1}{4}$  half-seconds. Or which amounts to the same thing, 571 ft in one  $\frac{1}{2}$  second & 1142 ft. in a whole second.

This, however, is the defined space traversed by sounds, if a current of the atmosphere blows across their path, & is their mean - progress a velocity.

But if the wind increases the rapidity of the sound, it is possible that it may traverse more than 600 ft. in the space of a  $\frac{1}{2}$  second; or on the other hand if the wind retard its motion it may not proceed more than 560 ft. in the same interval of time.

So, at length, I have brought to an end this memoir of mine, in which I have summarily embraced the principal observations I have made about the progress of sounds, and certain other things pertaining thereto.

Practical and ingenious men will not have much difficulty in applying this exposition to very many

ures which are not to be despised -  
But especially would the aforesaid ob-  
servations and experiments seem  
to conduce not a little to

1. The Philosopher, who, even because  
of them, will be in some respects  
better equipped for the investigation  
of the secret nature of sounds & for  
explaining their very numerous  
abstruse phenomena;

2. To the Sailor, who hence may learn  
how far off are the ships which he sees  
floating in the distance, or lying  
at anchor; how remote likewise may  
be the desired land or rock which he  
sees in the distance - facts which,  
from gun shots designedly fired on  
a given signal, may be easily &  
certainly known;

3. To the Soldier for the purpose of  
finding how far an enemy has  
placed his Camp; at what dis-  
tance an arsenal, a fort, or a

besieged cities &c as situated, for the purpose of planting against them siege cannon, and aiming mortars & bomb shells;

4. Is the Geographer, for more readily and certainly measuring the distances of places, because any body who is furnished with a small quantity of powder can, in this way, within an hour or two exhibit almost the whole of any region with a table most accurately outlined seeing that gunshots, as I have said, serve to mark distances by their firing, and any mathematical instrument by which angles are measured, either that common instrument which surveyors use, called the Plane Table, or a single rule, furnished with graduated scales, will indicate the situations of the various places, which afterwards can be easily delineated. In this way,

too one can readily inquire into the correctness & truth of maps, and if they have any errors he can correct them.

In fine, this method of observing sound, would be of great use in measuring distances of inaccessible places, especially of very wide rivers and places of that kind not otherwise easy to be measured. For a specimen of this work, I resolved with the aid of friends to compare the distances of certain among the more celebrated bays & straits, especially of the strait of Gradoes, between Tangier and Gibraltar, & the British Channel between Dover in England & Calais in France, where the breadth of the channel according to the measurement of ingenious Frenchmen, is 22.07 English miles. But the lamentable season of war through which we are passing, has interposed an obstacle to these undertakings & to others having for

their object the promotion of learning;

5. For the measurement of Echoes. Although very many learned men have anxiously inquired both anciently and in subsequent times concerning this amusing and pleasant phenomenon of sound, still there is not a good degree of harmony among them respecting very many things which relate to it, especially respecting the extent of space necessary for the repetition of one, two, three or more, syllables, or, what amounts to the same thing, respecting the space traversed by an echo in a certain interval of time. Mersenne allows . . . . . yards for the repetition of a monosyllabic sound.

Blancanus (?) allows 24 yards, to which our very celebrated countryman Dr. Plot gives his assent, but Athanasius Kircher asserts that nothing at all can be defined with certainty respecting it, because, forsooth the variation of the winds, the

intensification & the relaxation in the force of sound & many other things produce an immense variation.

It is not difficult, however, to offer an explanation of this disagreement among these distinguished men, for it can arise from very many causes — certainly from the slowness & from the different disposition of our senses, or from the various audibility of sounds; from the grave or acute sound of the syllables themselves, or from their protracted or prolonged pronunciation, or from any other cause which may protract the interval of time. I can have no doubt for instance, that if any sound reflecting object, should be able to reverberate all the syllables of this verse

*Vocalis Nympha quæ nec reticere loquente,\*  
it would not be able to reverberate  
all the syllables of the following*

verse, since its pronunciation is much more prolonged:

*Corpus adhuc Echo, non vox erat, et  
tamen resum\**

And still less would it be able to repeat all the harsh & prolonged syllables of the following verse:

*Arx tideris rostris Sphinx, praeter, torrida,  
seps, strix.*

But from the foregoing observations concerning the velocity of sound it may be concluded that echoes, like sounds, traverse certain & determinate spaces in a certain definite time. What I have myself frequently learned from experience is this, that an echo returns in double the interval of time in which the primary sound reached the sound-reflecting object. For example, if the sound-reflecting object was distant 600 ft., the return of the

\* Quoted from Ovid's Met., iii., lines 357-359 [Translator]

echo would take place within the same interval of time in which ~~is~~ which the primary sound would have traversed 1200 ft. if it had not been reverberated.

And this fact has often been of great use to me in measuring the distance of places. For example, when I was standing on the bank of the river Thames opposite of the town of Woolwich, the echo of a monosyllabic sound has been reverberated from the opposite houses in six half seconds from which I infer that the width of the River Thames at that point, from the margin of one bank to the margin of the other, is 1712 English feet, or over a quarter of a mile. For, as 9.25 half seconds : to 5280 in a mile :: so are six half seconds : to 3423.8 feet - the half of which is 1711.9 feet.

Finally, in this way, the height

of thunderclouds & of thunder itself may be easily ascertained.

Finis